HMS SCOTT RING LASER GYRO NAVIGATOR INTEGRATION

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Abstract- HMS SCOTT is a United Kingdom ocean survey vessel, that hosts a state-of-the-art deep ocean mapping system which was designed, developed and is currently maintained and periodically updated by the Space and Naval Warfare Systems Center, San Diego, (SSC-SD). The most recent update of this system, completed in late 2002, consisted of the replacement of an obsolete and very costly to maintain inertial navigation system. Another reason for updating the ship's inertial system was to provide higher accuracy attitude data, than was previously available with the old inertial system, to the high resolution multi-beam sonar system in order to produce improved bathymetric charts. After conducting a market survey of suitable inertial navigator systems, the Kearfott SEANAV Ring Laser Gyro Navigator, (RLGN), system, using a monolithic T-24 gyro, was selected to replace the old inertial system. The selection of the SEANAV RLGN was based on its relatively low cost, high reliability, and particularly the roll and pitch data accuracies of typically less than 1-arc-minute. This attitude data accuracy was key to enable a significant improvement in the bathymetry data accuracy. Two SEANAV systems were integrated with GPS receivers, a system master time code generator, and Electro Magnetic (EM) Log and Doppler Sonar speed sensors to provide the navigation portion of the mapping data. Operational testing of this updated system aboard HMS SCOTT in November, 2002, showed a marked improvement in the quality of the map product due in part to the improved attitude data provided by the SEANAV RLGN system.

I. INTRODUCTION

In 1995, the United Kingdom Ministry of Defence (UK Mod), approved construction of the 13,500 ton ocean survey ship, HMS SCOTT, shown in Fig. 1. The MoD specified that the ship was to be designed and built specifically to accommodate the U.S. Navy developed integrated Ocean Survey System. This system is comprised of four subsystems; Navigation, Sonar, Mission Control and Processing and Power.

Fig. 1. HMS SCOTT

The present HMS SCOTT navigation subsystem, shown in Figure 2. provides precise and accurate platform attitude, position and velocity information as a function of time for correlation with depth and other recorded oceanographic survey data to produce specialized charts. From 1997, when the ship was officially turned over to the Royal Navy, until 2002, the Miniature Ship's Inertial Navigation System (MINISINS), developed in the early 1970's was used to provide position, attitude and position data. This system, used extensively by U.S. Naval vessels and by the U.S. Naval Oceanographic Office survey fleet, was more than adequate for this purpose and was well supported. By the year 2000, MINISINS inertial measurement units, (IMUs) were beginning to fail at a rapid rate and, at the same time, logistic support, especially for IMU repairs, was becoming very costly. The high IMU failure rate, costly repairs, and long turn-around-times for repaired units to be returned to HMS SCOTT resulted in higher operating costs and loss of survey data. This prompted the investigation of a replacement inertial navigator for HMS SCOTT. An extensive market and technical survey was conducted and the Kearfott SEANAV RLGN was selected to replace the MINISINS. This selection was based on the relative low cost of the system ($110K), its advertised high reliability of more than 19,000 hrs MTBF, and its roll and pitch data accuracy of typically

0-933957-31-9

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 SEP 2003	**N/A**	**-**

4. TITLE AND SUBTITLE
HMS Scott Ring Laser Gyro Navigator Integration

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Space and Naval Warfare Systems Center, San Diego BS Bldg 175 53560 Hull Street San Diego, CA 92152-5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002146. Oceans 2003 MTS/IEEE Conference. Held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

less than one arc minute. This attitude accuracy was key to enable a significant improvement in bathymetric data accuracy. Fig. 3 shows a high level block diagram of the entire Ocean Survey System installed aboard HMS SCOTT.

II. SEANAV RLGN INTEGRATION

In 2002, two SEANAV RLGN systems were integrated with GPS receivers, a master time code generator and Electromagnetic Log and Doppler Sonar speed sensors on HMS SCOTT to provide the navigation portion of the mapping data. The sonar data is provided by a high resolution multi-beam (121 beam, 120 degree swath) sonar system. The high attitude accuracy provided by the SEANAV RLGN has enabled us to add a 361 beam resolution mode, that provides one-third degree resolution for the 120 degree swath.

Integration of the RLGN into the overall Navigation system required hardware and software changes in the VME Navigation Computer, development of a new Ship's Attitude Data Converter (SADC), the specification of three new RLGN output data messages on auxiliary I/O ports, configuration of the GVRC auxiliary I/O ports to send required GPS aiding data to the RLGNs, and modification of the Mission Control and Processing System (MCAPS) software to accommodate the changes resulting from replacing the obsolete inertial navigation system with the RLGN. Changes to the High Resolution Multi-Beam Sonar System (HRMBSS) were also required.

A. Navigation Computer Hardware Changes

In order to accommodate the RLGN systems, some of the serial I/O ports in the computer required reconfiguration from RS-232 to RS-422. As the I/O board used allowed this reconfiguration in blocks of four ports, existing interfaces had to be relocated to other I/O channels to allow the appropriate channel grouping to support the conversion. New cables were fabricated as required, and obsolete cables and equipment were removed.

B. Navigation Computer Software Changes

The Navigation Computer configures and controls the RLGNs, and reads, processes, and records the RLGN data. Since the RLGN commands are completely different from those of the inertial system that was replaced, this entire section of code had to be completely redone. Additionally, EM Log data had to be provided to each RLGN for use during brief GPS loss-of-signal periods. LORAN data processing was removed from the system for this update, therefore, all LORAN code was also removed from the Navigation Computer program. Changes were required to accommodate the I/O port relocations and new status and alarm messages from the RLGNs. New confidence test programs were developed to test the new interfaces.

C. Ship's Attitude Data Converter Development

The previous inertial navigation system provided attitude data in synchro format. The RLGNs provide digital attitude data. The new SADC is a PC device that receives attitude and heave data from both RLGNs, displays comparisons of roll, pitch, heading, and heave data for system performance evaluation, performs long-term data averaging for ship's trim monitoring, selects the preferred source of attitude for distribution to other OSS subsystems, and converts the digital attitude data to synchro format for the remaining users that require synchro data. Simulated attitude data is also available from the SADC for testing purposes. The SADC Computer Program is a completely new development for this installation, and includes confidence test programs to perform interface tests.

D. New RLGN Auxiliary Message Ports

In the previous system incarnation, the synchro attitude data was fed directly to the pitch compensator to correct the transmitted pulse for ship's pitch, and to the roll corrector to compensate the received returns for ship's roll motion. The synchro data was continuous and instantaneous. The RLGN attitude data are computed quantities, and are transmitted via a serial data link, resulting in latency delays. To minimize the latencies and to enable extrapolation of the roll and pitch data across the latency, the data to the pitch compensator, pitch and pitch rate, are sent to the pitch compensator 100 times per second on one I/O port, and the roll, roll rate, velocity, heading, heave, and extended precision UTC time are sent to the HRMBSS Computer on a separate port. Roll, pitch, heading, heave, and extended precision UTC time are sent to the SADC for use by all other users of attitude data on a third port. All three auxiliary ports are routed through the SADC. The data to the roll corrector and pitch compensator are switched by a relay board in the SADC, and only the selected data is passed on. SADC performs no processing of data from these two ports.

E. Configuration of the GPS VME Receiver Cards (GVRC) was required so that one of the auxiliary I/O ports on each GVRC communicated at 9600 BPS, RS-422, and was set to output the messages required by the RLGN, namely, the Time Mark Block 3 message, and an auxiliary message that provides a constellation change indicator. The Navigation computer program required modifications to perform the GPS receiver configuration as part of the RLGN initialization process. Additionally, the Navigation Computer Program provides commands for configuring an RLGN to use lever arm measurements that are dependent upon the location of the GPS antenna selected for the GVRC that is interfaced to that RLGN. Please note that the RLGN performs lever arm compensation on the GPS data it receives, while the Navigation Computer Program performs lever arm compensation for position data on the GPS data it receives.

F. Mission Control and Processing System Changes

The MCAPS consists of three functional groups:

Survey Control System (SCS),
System Analysis Station (SAS), and
Data Refinement System (DRS).

1) The SCS provides for central control and monitoring of the Navigation and HRMBSS subsystems. Mode changes, mission start and end times, data recording functions, and system status monitoring are conducted from this UNIX workstation. Changes to the SCS software were required to account for changes in the commands used to control the RLGNs, the deletion of the LORAN functionality, deletion of displays that were no longer needed, changes in the status monitor display, and changes in data formats. New confidence test programs were included in the SCS program to perform interface tests.

2) The SAS provides some of the same displays as the SCS, but this station is primarily used to display data plots to monitor system performance. This software was also modified to account for data format changes, deletion of the LORAN functionality, and removal of displays that were no longer needed. New confidence test programs were added to the SAS program to perform tests on the new interfaces.

3) The DRS workstation is used to post-time process the navigation and sonar data, create the Bathymetric Navigation Charts, and to perform various utility calculations and functions, such as listing the contents of data tapes and copying tapes. With the installation of the RLGNs, much of the navigation data editing was no longer required, as the real-time performance of the tightly coupled RLGN/GPS was as good as the post-time Kalman smoothed data from the previous system, which was very loosely coupled to GPS. The features that were no longer needed to process the new data were retained for reprocessing older data, but new programs were developed to perform time regression analysis and invalidation of bad data using the new data formats. The lister and tape copy programs were modified to work with the new data formats. New confidence test programs are included in the DRS program to perform interface tests.

G. HRMBSS Hardware Changes

The High Resolution Multi-Beam Sonar System is designed to compensate the transmitted signal for ship's pitch motion and the received signals for ship's roll motion, to ensure that the center beam is vertical below the ship. The previously used MINISINS inertial navigation system produced synchro outputs of attitude data, which were fed directly to the roll corrector and pitch compensator in the sonar system. The RLGN outputs digital attitude data, so modifications were required to the roll corrector and pitch compensator to enable the use of the digital inputs. The HRMBSS Computer now receives the digital roll and roll rate message, performs the extrapolation to correct for the data latency, and outputs the roll data to the roll corrector via a SPAWAR designed interface card. Pitch and pitch rate data is now fed to the pitch compensator via a SPAWAR designed interface card.

H. HRMBSS Software Changes

Due to the changes in the Navigation system, data previously fed to the Sonar system from the Navigation Computer are now fed directly from the RLGN, resulting in the removal of the old interface. Capability was added to the Sonar program to compute, display in two and three dimensional screen plots, and record, the 361 beam data, in addition to the 121 beam data that is the normal sonar product. Presently, the current on-board DRS tools do not support editing and processing of the 361 beam data. The 361 beam solution was installed to permit preliminary evaluation of this new feature, and to produce data tapes that can be used when the new tools are available. New confidence test programs were developed to perform tests on the new interfaces.

III. LESSONS LEARNED

The preceding sections demonstrate that the transition from MINISINS to the SEANAV RLGN required considerable effort on the part of SPAWAR personnel. During the integration and testing phase, we learned a number of things about the GVRC GPS receiver I/O messages, the original SEANAV firmware, and the RLGN performance, which required modifications to the SEANAV firmware and our SPAWAR developed software.

A. GVRC Interface

The RLGN was designed to interface with a PLGR GPS receiver, which can be ordered embedded in the SEANAV package. The PLGR is a 4 channel receiver that locks onto one satellite per channel. The Time Mark Block 3 message from the PLGR is what the SEANAV firmware was designed to receive. The GVRC receiver modified the message to account for the increased number of channels (6), and channels 5 and 6 alternate between several satellites. Up to 8 satellites are used in the fix solution, so additional information is required in order to determine if a change in constellation has occurred. Such a signal is provided, but the receiver had to be configured to output this message in addition to the Time Mark Block 3 message, and the SEANAV firmware had to be reprogrammed to use it. Additional difficulty arose when we discovered that the receiver reference specifications did not accurately reflect the actual message format. This was resolved following considerable testing and communication between SPAWAR and the manufacturers of the SEANAV and GVRC.

B. EM Log Interface

The EM Log interface was not originally included in our version of firmware, as normally one I/O port is assigned to a function, regardless of the fact that most of ours were output only. We had assigned all of the available ports. EM Log data is used by the RLGN Kalman Filter to slow the rate of drift during a GPS outage. Since HMS SCOTT operates for up to 35 days per survey, they occasionally encounter some GPS outages, so it is important to keep system errors within survey

specifications during those occasions to prevent having to turn around to rerun the survey line when GPS coverage is restored. This was resolved by another firmware modification to input EM Log data on the input channel of one of the auxiliary I/O ports.

C. UTC Resolution

Universal Coordinated Time (UTC) time is output on two of the auxiliary ports. We found that the standard format provided did not yield sufficient resolution to time tag the data to the hundredth of a second, the rate at which the data is being sent. This required a firmware modification to add another byte of time data at the end of the message to achieve the required resolution.

D. At-Sea Alignment

Upon using the RLGNs at-sea, we discovered that starting the systems in anything but the most benign sea conditions would cause the systems to fail to complete the coarse alignment phase of the startup sequence. The failure to align was due to a combination of very long lever arms and the fact that coarse alignment uses GPS velocities, and the models in the Kalman filter do not account for the velocity components introduced by roll and pitch due to the lever arms. Therefore, whenever the measured velocity differences exceeded the filter design values, the filter solution failed to converge. Two methods were tried to resolve this issue. Method 1 was to loosen the filter to accept larger velocity differences. While this method did allow alignment in fairly rough seas, it had the side effects of increasing settling time, and it caused the terms used to compute the circular error probability to increase, resulting in an error estimate that was excessive. Method 2 was to enter a heading, either from the other RLGN or via manual entry, when entering the command to initialize the system. This method worked as desired, and was retained as the normal at-sea RLGN startup procedure. Implementation of this command required modification to the SPAWAR developed Navigation program.

E. Heave Data Output

The SEANAV system was not designed to output true heave information, but rather vertical distance, either referenced to Mean Sea Level or GPS altitude. Due to an oversight, our units were programmed to reference the vertical distance to GPS altitude. Monitoring two systems in our laboratory overnight, we observed a 50 foot cyclical drift in this quantity over time. Another firmware change was needed to reference the vertical distance quantity to Mean Sea Level. Following this update, observations revealed much better performance, but drift between two units sitting side-by-side was observed to be 4-to-6 feet, still not usable to compensate the sonar data for the effects of heave motion. A contract with Kearfott to modify the firmware to include the classic surge, sway, and heave filter implementation, has been negotiated. This firmware modification should produce heave data that satisfies survey requirements. This contract also covers the firmware implementation of the following item.

F. Automatic Gyro Bias Updates to EEPROM

The SEANAV, and the essentially similar land units, were, prior to installation on HMS SCOTT, used for missions of less than 1 day duration. Upon startup, the system uses data stored in electrically erasable programmable read-only memory (EEPROM) to initialize the unit. If the gyro bias data stored in the EEPROM is close in value to the actual drift in the gyro, the system settles quickly after one or two 90 degree turns. If the stored data does not reflect the actual gyro characteristics due to drift since the data was stored, many more maneuvers are required to settle the system, especially in heading. The observed difficulty stems from the requirement to issue a shutdown command, followed by removing power from the system, in order to write the data into EEPROM. Also, to prevent a bad run from grossly ruining system performance, only 20% of the Kalman filter derived gyro bias corrections are applied at each shutdown command. Thus, if the parameters in memory are way off, many shutdowns of the system must be performed to get the memory updated sufficiently. Each time the system is shut down, the potential exists for a discontinuity in the position data to occur, which adversely affects the map data quality. In addition, the process places an extra burden on the operators, who are also performing other data collection, logging, and analysis chores. Failure to perform the steps of switching to the backup RLGN, then entering the shut command and powering down the system in the proper order, or accidentally powering down the wrong RLGN, could result in loss of survey data. To resolve this difficulty, the contract mentioned in the previous item will provide firmware changes to periodically update the EEPROM with computed gyro bias corrections without requiring the operator to cycle power or issue the shutdown command.

IV. CONCLUSION

The Kearfott SEANAV RLGN, Model KN-5053 has proven to be an excellent performer for both position and attitude when integrated into the HMS SCOTT Ocean Survey System suite. The attitude performance has allowed us to push the sonar resolution to 361 beams, equal to one-third degree. We anticipate that the firmware upgrades expected in the next few months will resolve our outstanding issues.

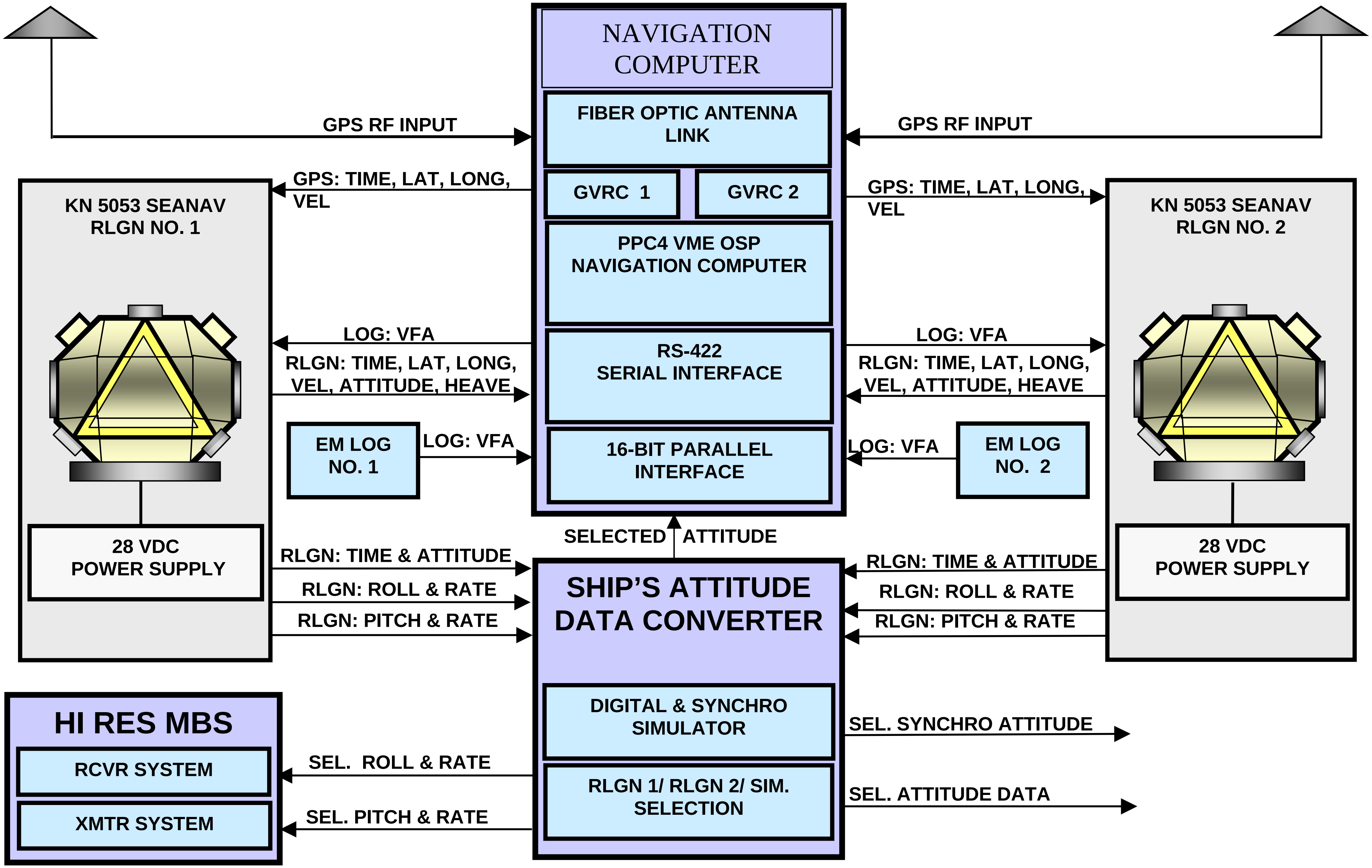

Fig. 2. Navigation System Block Diagram

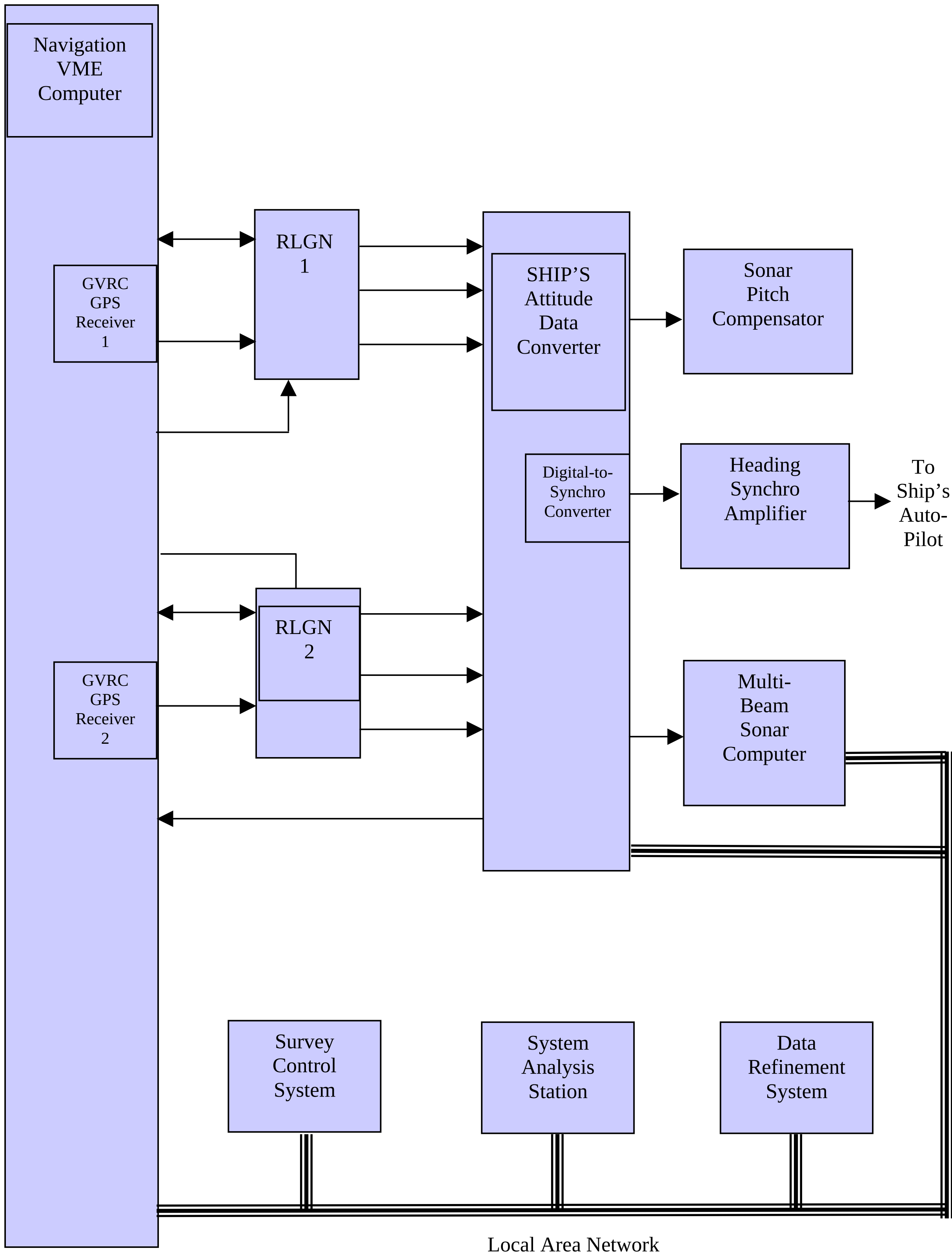

Fig. 3. Simplified Ocean Survey System Block Diagram